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AN OCCURRENCE OF TRACHYTE ON THE ISLAND OF HAWAII.[1]

THE Hawai an Islands are commonly described as consisting almost wholly of basaltic lavas, though in truth there is a known wide range in the rocks thus broadly characterized. These lavas have issued as flows from many centers, building up great volcanic mountains. The eruptions have continued for a long time with gradually shifting scene of action, and agencies of degradation have reduced some ancient basaltic mountains to mere reefs, while other volcanic piles are now like deeply dissected models, showing their constitution to the very core. With all this opportunity to examine the products of Hawaiian volcanoes of various epochs and at many centers, no one has, to the writer's knowledge, found and described any other than basaltic or related lavas as existing in the entire group. However, during the summer of 1902, while the writer was engaged in a reconnaissance of the Hawaiian Islands for the Geological Survey, he was fortunate enough to discover an occurrence of trachyte which, from several standpoints, seems to merit description.

The locality at which this unique rock was found is on the island of Hawaii, at the northern base of Mount Hualalai, one of the great basaltic volcanoes of the island, the last eruption of which took place in 1801, from a low-lying point near that at which the trachyte occurs. The accompanying map shows the geographic position of the trachyte locality.

Mount Hualalai is a basaltic cone of the Mauna Kea type, rising 8,000 feet above the sea, consisting mainly of lava flows, but dotted with numerous small cinder cones and punctured by perhaps as many remarkable "pit craters." The cinder cones are most numerous near the summit of the mountain, and, so far as the writer is aware, the products of all these recent and local outbursts are basaltic in character. The later lavas on the northern slope are olivine-rich plagioclase basalts.

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[1] Published with the permission of the Director of the United States Geological Survey.

Near the northern base of Mount Hualalai is a tuff cone, notably larger than those on the upper slopes of the mountain, and forming a very striking feature of the landscape as seen from the north. This cone, called Puu Waawaa, seems at first, like many others, an excrescence on the surface of the larger volcano, but the material of which it is made is the trachytic lava to be described, and it is a matter for future observation to determine whether the situation relative to Mount Hualalai is not, as the writer suspects, quite a matter of chance. The base of Puu Waawaa is at about 3,300 feet above the sea and its summit several hundred feet higher. Adjacent to the cone of Puu Waawaa on the north, and extending west of north for

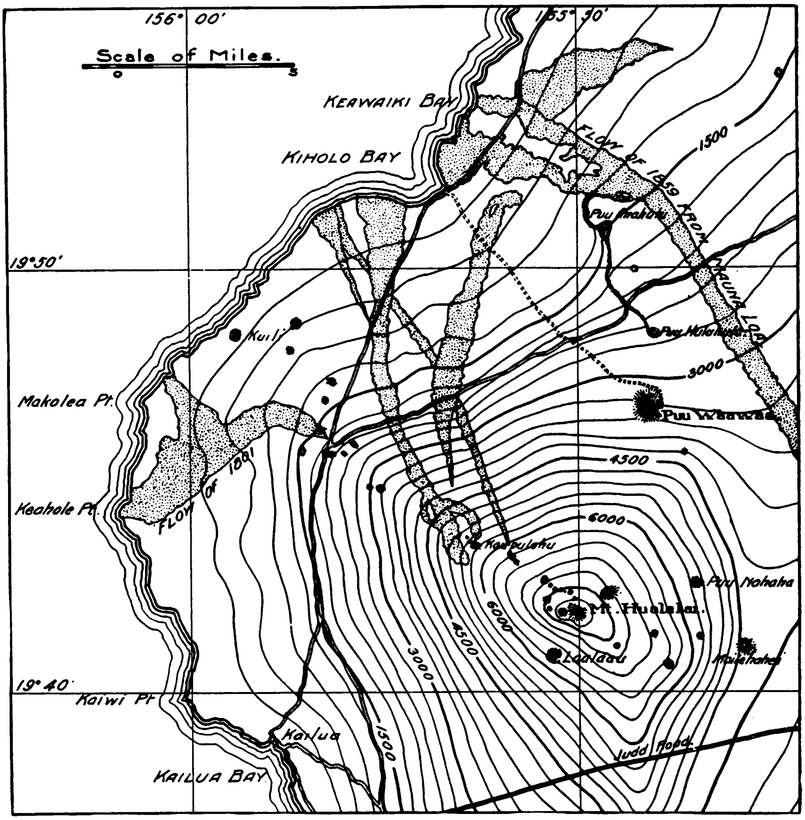

FIG. 1.—Map of a portion of the island of Hawaii.
(From map issued by Hawaiian Government Survey.)

three miles, is a very clearly defined bench or terrace with abrupt western border and northern end. A small point on its surface gives the name Puu Anahulu. This bench is indicated on the map by the hachures marking its steep western slope.

On the south the terrace of Puu Anahulu merges with the low grade slopes of Mount Hualalai and on the east with the surface of still smaller angle down which lava flows have come from Mauna Loa, some thirty miles away. Some of the late flows from Mount Hualalai have spread over the terrace, and in places have fallen in a stony cascade down the steep western bank. Others from the same source have passed between the terrace and the cone of Puu Waawaa. Some from Mauna Loa have also poured over portions of the bench or passed around its northern end to the sea. Puu Waawaa has been encircled by lavas from Hualalai which have cut it off from the terrace.

The terrace bench of Puu Anahulu is made up, so far as observations go, of an agglomeratic aggregate of large and small fragments of the rock to be described. In general, this rock is much decomposed by kaolinization, only the larger fragments still consisting in part of dark gray material. The softer, light-colored rock has been used for road metal on the new government road from Waimea to Kona, which passes over this bench. Both the bleached and the darker rock exhibit a rude schistosity due to a parallel arrangement of minute feldspar tablets, like that common in phonolite and in some trachytes.

Puu Waawaa is scored by numerous radial ravines penetrating its slopes for fifty feet or more, and in all of them examined the typical structure of a tuff cone is revealed. The cone seems to be made up of tuffs of varying texture, well stratified, and dipping nearly with the slope of the cone. Most of the tuff is made up of ash or fine gravel, with angular fragments irregularly distributed through it, which rarely exceed a few inches in diameter.

The fragments consist of brown pumice, dark aphanitic, or black obsidian-like rocks, with some showing a mingling of the latter materials. The dark aphanitic fragments are not unlike some dense basalts of the island in appearance, yet resemble also the freshest rock from the bowlders of Puu Anahulu.

Thin sections of the obsidian show it to be a colorless glass containing streams of feldspar microlites in some parts and free from them in others. The dull aphanitic streaks and masses are largely crystalline, with more or less of fine magnetite dust and ferritic globulites, and a colorless glassy base of variable amount.

To ascertain the chemical character of this rock an analysis was made by Dr. Hillebrand of the black glassy portion, with the result given in column 1 of the subjoined table. It is clearly an almost anhydrous, trachytic obsidian of close relationship to many other known rocks, of which analyses are also given in the tables, a resemblance which will be discussed in a later paragraph.

There is every reason to suppose that the associated pumice is of the same character as the obsidian, since no other rocks were observed among the fragments of the tuff.[1]

Turning now to the rock occurring in fragments at Puu Anahulu, microscopical examination shows it to be a felsitic trachyte, holocrystalline in the specimens examined, of typical trachytic texture. The feldspar microlites forming the greater part of the rock are mainly very small, averaging but 0.02–0.05^{mm} in thickness, less than 1^{mm} in length, and, while some are prismatic, many are more or less tabular in shape, causing by their nearly parallel fluidal arrangement the characteristic semi-schistose texture of the rock, which has already been commented upon.

The feldspars are fresh, and among them may be recognized sanidine, anorthoclase, and probably albite. The sanidine forms somewhat larger microlites than the anorthoclase and albite, but a distinct porphyritic texture was not observed.

The feldspars make up more than four-fifths of the trachyte. The norm of the obsidian analyzed indicates a possible content in nephelite for the perfectly fresh rock, but a careful search for this mineral failed to reveal it in the sections of the somewhat altered Anahulu trachyte. The remainder of the rock consists of magnetite and apatite, in small amounts, and two or more undetermined minerals which occur for the most part in the angular interstitial spaces between

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[1] The writer's observations at Puu Waawaa were necessarily quite limited and leave much to be desired. He did not have time to explore the cone thoroughly, but from the facts noted on the north and east slopes, it seems probable that Puu Waawaa is composed solely of tracyhte tuff.

ANALYSES OF HAWAIIAN TRACHYTES AND ALLIED ROCKS.

No.	1	2	3	4	5	6	7	8
SiO_2	62.19	62.11	64.28	62.70	60.50	57.52	60.39	63.09
Al_2O_3	17.43	*w*	15.97	16.40	16.86	18.46	22.57	18.44
Fe_2O_3	1.65	*w*22.97	2.91	3.34	1.67	2.23	0.42	2.90
FeO	2.64	*w*	3.18	2.35	2.54	2.44	2.26	1.36
MgO	0.40	......	0.03	0.79	1.11	1.08	0.13	0.16
CaO	0.86	0.85	0.85	0.95	2.95	2.12	0.32	1.00
Na_2O	8.28	6.89	7.28	7.13	6.46	7.58	8.44	7.25
K_2O	5.03	4.82	5.07	5.25	5.42	4.08	4.77	5.23
H_2O+	0.39	1.60	0.20	0.70	1.40	1.80	0.57	0.62
H_2O-	0.14		......	......	......	......	......	0.21
CO_2	0.02	trace	......	......	0.70	......	trace	......
TiO_2	0.37	......	0.50	0.92	0.75	0.92	......	0.45
ZrO_2	0.04	......	......	......	......	......	......	......
P_2O_5	0.14	......	0.08	......	0.21	0.21	......	......
SO_3	none	......	......	......	......	......	......	......
Cl	......	......	0.12	......	......	......	......	......
Cr_2O_3	trace	......	......	......	......	......	......	......
NiO	none	......	......	......	......	......	......	......
MnO	0.32	......	trace	......	0.20	......	0.08	......
BaO	0.03	......	none	......	......	......	......	......
SrO	none	......	trace	......	......	......	......	......
Li_2O	trace	......	trace	......	......	......	......	......
	99.93	......	100.33	100.53	100.77	99.64	99.95	100.77

No.	9	10	11	12	13	14	15	16
SiO_2	61.08	66.22	63.24	66.50	63.20	60.11	63.76	66.06
Al_2O_3	18.71	16.22	17.98	16.25	17.45	19.01	17.37	16.46
Fe_2O_3	1.91	1.98	2.67	2.04	3.60	4.63	0.10	2.25
FeO	0.63	0.16	0.85	0.19	......	0.37	1.11	1.10
MgO	0.08	0.77	0.63	0.18	0.75	0.23	0.93	0.19
CaO	1.58	1.32	0.93	0.85	1.40	0.66	1.72	0.79
Na_2O	8.68	6.49	6.27	7.52	6.90	6.53	6.69	6.81
K_2O	4.63	5.76	5.47	5.53	5.88	5.36	5.97	5.52
H_2O+	2.21	0.24	0.80	0.50	0.50	1.37	0.40	0.62
H_2O-	......	0.08	0.37	......	......	......	......	
CO_2	......	......	......	......	......	0.84	......	......
TiO_2	0.18	0.22	0.38	0.70	0.46	0.96	0.70	......
ZrO_2	......	......	......	......	......	......	......	......
P_2O_5	......	0.10	0.22	......	......	......	0.16	......
SO_3	......	0.02	......	......	......	......	......	......
Cl	0.12	0.04	......	......	......	......	......	......
Cr_2O_3	......	......	none	......	......	......	......	......
NiO	......	......	......	......	......	......	......	......
MnO	......	......	0.04	0.20	......	......	0.37	0.55
BaO	0.05	0.29	0.25	......	......	......	......	......
SrO	......	0.06	0.03	......	......	......	......	......
Li_2O	......	trace	......	......	......	......	......	......
	99.86	99.97	100.14	100.46	100.14	100.07	99.28	100.35

LIST OF ROCKS IN TABLE OF ANALYSES.

Rock	Locality	Analyst
1. Trachyte obsidian.......	Puu Waawaa, Hawaii........	W. F. Hillebrand
2. Trachyte...............	Puu Anahulu, Hawaii........	W. F. Hillebrand
3. Glaucophane-sölvsbergite	Cape Ann, Massachusetts....	H. S. Washington
4. Hornblende-sölvsbergite..	Laugendal, Norway.........	L. Schmelck
5. Hedrumite..............	Östö, Norway...............	V. Schmelck
6. Foyaite.................	Gran, Norway...............	L. Schmelck
7. Litchfieldite............	Litchfield, Maine............	L. G. Eakins
8. Pulaskite...............	Salem Neck, Massachusetts...	H. S. Washington
9. Phonolite...............	Devil's Tower, South Dakota.	L. V. Pirsson
10. Quartz-syenite-porphyry .	Bearpaw Mountains, Montana......................	H. N. Stokes
11. Biotite-trachyte.........	Yellowstone Park, Wyoming .	W. F. Hillebrand
12. Lestiwarite.............	Laugendal, Norway..........	V. Schmelck
13. Nordmarkite............	Tönsenas, Norway..........	G. Forsberg
14. Bostonite...............	Laugendal, Norway.........	V. Schmelck
15. Pyroxene-syenite........	Kunsamo, Finland..........	N. Sahlbom
16. Riebeckite trachyte......	Berkum, Germany..........	H. Laspeyres

the feldspars and much less abundantly in minute stout prisms. The two most distinct minerals are respectively colorless and clear pale yellow, of strong refraction and double refraction, approximately like diopside or acmite. Extinction is parallel for the colorless prisms and never more than 10° for the yellow ones. There is no visible pleochroism in either, hence lovenite seems to be excluded. The norm of the glassy rock shows the acmite molecule, but no recognizable acmite, aegirite, or riebeckite has been noticed. As the analysis shows zirconia and titanic acid in determinable quantities, it is possible that rare or unknown zirco- or titano-silicates are present. Clear glass and dark globulitic areas are present in small amount.

A glance at this trachytic rock suggests its close relationship with the obsidian of Puu Waawaa. It is not sufficiently fresh, as to its dark constitutents, to warrant full analysis, but the feldspars are only slightly attacked, and a partial analysis by Dr. Hillebrand, given in column 2 of the table, demonstrates sufficiently the practical identity of the two rocks.

The position of the obsidian in the *Quantitative Classification of Igneous Rocks*[1] is shown by the norm calculated from the analysis, which is as follows:

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[1] WHITMAN CROSS, JOSEPH P. IDDINGS, LOUIS V. PIRSSON, AND HENRY S. WASHINGTON, *Quantitative Classification of Igneous Rocks*, Chicago, 1903.

Orthoclase	29.47	Salic molecules, 86.74
Albite	51.87	$\frac{\text{Sal.}}{\text{Fem.}}=6.92$
Nephelite.	5.40	
Acmite	4.62	Femic molecules, 12.45
Na_2SiO_3	0.61	
Diopside	2.88	
Olivine	2.63	
Fayalite	0.61	
Ilmenite	0.76	
Apatite	0.34	
	99.19	
Etc.	0.62	
	99.81	

As the ratio between salic and femic molecules of this norm is 6.92:1, or slightly less than 7:1, the rock falls within the Dosalane Class. Since the feldspars predominate over nephelite to an extreme degree and there is no anorthite in the norm, the rock falls in the perfelic order *germanare*, and the peralkalic rang *umptekase*. Soda strongly dominates potash, and thus the glass belongs in the subrang *umptekose*, but is so close to the corresponding subrang of the Persalanes that the position is best shown by the name *nordmarkose-umptekose*.

The partial analysis of the trachytoid rock shows that to belong also in the subrang *umptekose*.

Local interest of the discovery.—The discovery of this lava rich in alkali feldspar, so far removed petrographically from the basalts and allied rocks hitherto supposed to be the only products of volcanoes on the island of Hawaii, raises primarily a question of much local interest. The modes of occurrence, described above, suggest that there may have been quite extensive eruptions of these lavas. Unfortunately, these rocks were found just at the close of my visit to the island of Hawaii, and I was unable to search for further occurrences. The terrace-like bench of Puu Anahulu is certainly a remnant of a topography carved out of the trachytic rock, and it may well be that beneath the basaltic flows from Mauna Kea, Mauna Loa, and Mount Hualalai there is an ancient trachytic island. So far as I am aware, however, no fragments of trachyte have been found in the more recent basaltic lavas. In those of Mount Hualalai I observed only inclusions of dunite, olivine-gabbro, pyroxenite, and basic augite-andesites.

If further exposures of the trachytoid rocks are found, it seems to me probable that they will be in the area of the Waimea plain which extends practically from Puu Anahulu for twenty miles northeasterly to the north base of Mauna Kea, or in the northern and oldest basaltic section of the island, the Kohala Mountains.

Trachytic cones like Puu Waawaa may exist near the bases of Mauna Kea or Mount Hualalai. Their materials, if of the black glass or aphanitic rock described, might naturally be considered as basaltic, if not subjected to chemical examination.

Puu Waawaa has the appearance of being a cone built up by explosive eruption of one short period, like the scores of basaltic cones which dot the slopes of Mauna Kea and Mount Hualalai, and which seem to belong to a period of local volcanism following that of lava outpourings. The materials of Puu Anahulu is agglomerate-like and is certainly not a part of a simple flow, but its crystalline texture shows also that it is not like the tuffs of Puu Waawaa. In all probability, therefore, there was in the comparatively remote past of the island of Hawaii a period of trachytic eruptions of a magnitude not now to be ascertained, but possibly of much importance.

A broader significance of this discovery is connected with the history of the Hawaiian group. While no one of the larger Hawaiian islands has been thoroughly investigated as to the range in composition of the lavas which have built it up, it is hardly probable that trachytoid rocks occur upon them. It is, therefore, highly interesting that the most recent island of the group, Hawaii, should exhibit this unique rock.

In discussion of this question, it must be understood that the island of Hawaii is not only the largest, but is also, in the current view, the youngest, and lies at the extreme southeastern end of a zone of oceanic islands which geologically belong together, extending for fifteen hundred miles or more to the west-northwest, toward the coast of Japan. The larger islands, commonly referred to in speaking of the Hawaiian group, are all located in the eastern end of this zone. The smaller ones, stretching out for more than a thousand miles, farther, are, in part at least, known to be remnants of former volcanic piles now reduced by erosion in some cases to mere reefs. So far as I have found statements concerning this long train of islets, they are basaltic, excepting the coral-reef rock. The inference drawn by many geologists who have considered the matter is that all these islands are the products of a long cycle of volcanic eruptions producing similar lavas. It appears to me plausible to assume that the earliest eruptions occurred at or near the western limit of this zone, and that, in a general way at least, the centers of activity have developed successively farther and farther to the east or southeast, until now the only active loci of eruption are those of Mauna Loa and Kilauea on the island of Hawaii.

A somewhat different view was taken by J. D. Dana, who has said:

> There is reason for believing that the fires along the Hawaiian line broke out all together at some time in the long past, but only Hawaii has kept on piling up lava streams from that remote time of outbreak until now, and hence has come the altitude of these loftiest volcanic mountains of the Pacific.[1]

Dana recognized, however, that Kauai and Oahu, the most northwesterly of the larger islands, exhibit great erosion. It is also a fact that both these islands are dotted by cinder cones, some of them with craters of model-like form, situated in such independent relation to the topographic forms produced by the great erosion that their later age is unquestionable.

Whatever the point of first eruption may have been, this volcanic cycle began in a remote geologic epoch, not now determinable, but there are grounds for believing that it may well have been in the early part of the Tertiary period. The chief evidence bearing on this point consists in the destruction of the older centers by enormous and long-continued erosion, the existence of the later tuff cones mentioned, and the fact that the raised reef of beach deposits abutting against the Diamond Head crater, on the island of Oahu, contain fossils considered by Dr. W. H. Dall to be of late Pliocene or early Pleistocene age. The crater of Diamond Head, however, is but one of many small centers of tuff eruption, belonging to the comparatively recent and feeble epoch of volcanic activity. Oahu may be, moreover, one of the younger islands of the long Hawaiian chain.

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[1] *Characteristics of Volcanoes*, pp. 357, 358.

The magnitude of the erosion by which the mountains and valleys of Kauai and Oahu have been carved out of former basaltic piles cannot now be measured. All writers upon these islands have recognized that erosion has been great. The imposing cliffs or *pali* which face the sea upon both islands, the canyons with walls 2,000–3,000 feet in height, the general ruggedness of mountain contours, are comparable in scale with the same features of the Rocky Mountain country. The erosion periods of the two districts must also be comparable. The former volcanic centers are rudely indicated by the attitude of lava flows, but enormous sections of the old volcanoes have been engulfed by faulting or wholly destroyed by erosion.

The discovery by Dall of marine fossils in a raised reef or beach rock about Diamond Head, the well-known tuff crater near Honolulu, fixes a datum point in the history of Oahu which is manifestly of great importance. Close determination of the age of the fossiliferous deposit is at present impossible because, to quote Dr. Dall,

> we have no standard of comparison in the whole Polynesian region by which the species could be compared with those of Tertiary beds of known age; but the fossils have every characteristic of those generally assigned to the Pliocene or upper Miocene in their general aspect, and state of fossilization. . . . . To sum up, it is concluded that the reef rock of Pearl Harbor and Diamond Head limestones are of late Tertiary age, which may correspond to the Pliocene of west American shores, or even be somewhat earlier.[1]

The view of Dr. Dall that "the whole mass of Diamond Head had been slowly deposited in comparatively shallow water and gradually elevated without being subjected to notable flexure" seems to the writer incorrect for various reasons, some of which have been pointed out by Dr. J. C. Branner[2] and Dr. S. E. Bishop.[3] This point is not here at issue, for whatever the relations of the marine deposits to the Diamond Head tuffs, they exist and are younger than the great erosion of Oahu. Even if of early Pleistocene date, they indicate that the enormous denudation of the Oahu volcanoes must be referred to the late Tertiary and the lava eruptions themselves to a still earlier period.

From the considerations above presented it appears that the

[1] *Loc. cit.*, pp. 58, 60.

[2] *American Journal of Science*, Vol. XVI (1903), pp. 306, 307.

[3] *American Geologist*, January, 1901.

Hawaiian volcanic province was characterized by basaltic or allied lavas for a very long geologic period, and that in comparatively recent times the first highly siliceous and feldspathic magma appeared. Even now the basaltic emissions continue with no known recurrence of the trachytic magma.

General significance of the occurrence.—The long sequence of basaltic or allied lavas, which has probably occupied a long geologic period, is in striking contrast with the succession of widely differing lavas, ranging from highly siliceous and alkalic rocks like rhyolite or trachyte, to basic basalts, produced during the same time in various continental provinces adjacent to the Pacific Ocean. To be sure, there is much greater variety in the dark Hawaiian lavas than is implied in the common term given them, but this trachytic magma is certainly highly exceptional, if indeed there has ever been another eruption of equally salic material in the history of the group.

To the modern petrographer this occurrence must at once suggest many interesting problems of petrogenesis. One of these will be the query as to whether magmatic differentiation has produced this unusual lava or not. The extreme advocates of this process, concerning which so much has been assumed and so little proved, will no doubt treat it as a matter of course that this magma, so exceptional for the Hawaiian province, is one of the complementary products of differentiation. This view has, however, not much to support it in the history of the older centers, and until further examination of the chemical characters of the "basalts" of this province have been made elaborate discussion of this point has no good foundation. It remains a matter for speculation as to why the process of differentiation has not long ago produced a greater variety of lavas, or, assuming that the differentiation has taken place, why the products have not been emitted at the more recent centers of volcanic activity. Directly connected with these questions arises also that of possible fundamental differences between the subjacent magmas of the Hawaiian and the continental provinces.

In all of these problems the relations of the Hawaiian trachyte to similar rocks of other localities will be of use. The table already presented gives a series of analyses of allied rocks, and in that following are the norms calculated from those analyses. The latter table brings out the fundamental chemical relations of these varied rocks and their positions in the *Quantitative System of Classification.* The current names assigned to these rocks are those of the authorities quoted.

The nordmarkose-umptekose rock of Hawaii is shown by the table to be nearly akin in its chemical characters to other rocks of varying occurrence and texture in widely separated parts of the world. The textural differences and those due to the distinguishing rôles played by quantitatively subordinate constituents have led to a variety of names, obscuring the fundamental similarity of the magmas.

Considering the trachyte of Puu Waawaa as a possible differentiate of an underlying parent magma, it is interesting to note that the associations of the chemically similar rocks of the table are widely different. Several of the rocks compared belong in the grorudite-tinguaite series described by Brögger from the Christiania region of Norway.[1] Others are from the similar petrographic province of

NORMS OF ROCKS COMPARED WITH THE HAWAIIAN TRACHYTE.

MOLECULES OF NORM		UMPTEKOSE				
		"Foyaite" (Brögger) Gran, Norway	"Hornblende sölvsbergite" (Brögger) Laugendahl, Norway	"Hedrumite" (Brögger) Östö, Norway	"Glaucophane sölvsbergite" Cape Ann, Mass. (Washington)	"Trachyte" Puu Waawaa
SALIC MOLECULES	Corundum	....	....	....	....	....
	Quartz	....	....	....	2.0	....
	Orthoclase	23.9	31.1	32.2	30.0	29.5
	Albite	50.3	55.0	46.1	53.4	51.9
	Nephelite	7.4	....	4.5	....	5.4
	Anorthite	4.4	....	0.8	....	....
FEMIC MOLECULES	Acmite (& Na_2SiO_3)	....	4.6	....	6.9	5.2
	Other silicates	7.2	5.0	10.7	6.5	5.5
	Oxides of iron, etc.	4.9	4.3	3.7	1.6	1.1
	Apatite	....	....	....	....	....
	Titanite, etc.	....	....	....	....	....
Total salic molecules		86.0	86.1	84.6	85.4	86.8
Total femic molecules		12.1	13.9	14.4	15.0	12.5

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[1] *Die Eruptivgesteine des Kristianiagebietes,* "Die Gesteine der Grorudit-Tinguait-Serie" (Kristiania, 1894).

NORMS OF ROCKS COMPARED WITH THE HAWAIIAN TRACHYTE—(*Cont'd*)

	MOLECULES OF NORM	NORDMARKOSE									
		“Bostonite” (Brögger) Hedrum, Norway	“Nordmarkite” (Brögger) Tönsenäs, Norway	“Lestiwarite” (Brögger) Laugendahl, Norway	“Pyroxene-syenite” (Hackmann) Finland	“Riebeckite trachyte” (Rosenbusch) Berkum, Germany	“Biotite-trachyte” (Hague & Jagger) Yellowstone Park	“Quartz-syenite-porphyry” (Weed & Pirsson) Bearpaw Mountains, Montana	“Phonolite” (Pirsson) Devil's Tower, South Dakota	“Pulaskite” (Washington) Salem, Massachusetts	“Litchfieldite” (Bayley) Litchfield. Maine
SALIC MOLECULES	Corundum	1.2	....	....	....	....	....	....	....	....	2.9
	Quartz	....	....	4.7	....	4.5	2.8	5.3	....	....	....
	Orthoclase	31.7	35.0	32.8	35.6	32.8	32.8	33.9	27.2	31.1	28.4
	Albite	55.0	48.2	52.4	52.4	53.5	52.9	51.9	54.0	59.2	52.4
	Nephelite	....	5.4	....	2.0	....	....	....	10.5	1.1	10.2
	Anorthite	3.2	....	....	....	....	4.4	....	1.1	2.0	1.7
FEMIC MOLECULES	Acmite (& Na$_2$ SiO$_3$)	....	1.4	6.0	0.5	3.7	....	2.8	....	....	....
	Other silicates	0.6	8.3	1.5	6.7	3.3	1.6	3.0	2.9	1.8	3.1
	Oxides of iron, etc.	5.4	0.9	0.5	1.2	1.4	4.0	1.3	2.4	4.7	0.7
	Apatite	....	....	....	....	....	....	....	....	....	....
	Titanite, etc.	....	....	1.2	....	....	....	....	....	....	....
Total salic molecules		91.1	88.6	89.9	90.0	90.8	92.9	91.1	92.8	93.4	95.6
Total femic molecules		6.0	10.6	9.2	8.4	8.4	5.6	7.1	5.3	6.5	3.8

Essex county, Mass., where there is a great variety of rocks, discussed in their genetic relations by Washington.[1] No one of the rocks of the table occurs in an association comparable with that of the Hawaiian trachyte. The occurrence here described seems to be a notable one, requiring consideration from the advocates of the view that a natural or genetic classification of igneous rocks may be worked out from the study of their associations. The recent tabulations of chemical analyses of igneous rocks by Washington[2] and Iddings,[3] according to the *Quantitative System*, bring out many similar significant facts, to be taken into account in this discussion. They show the essential identity of many magmas having widely different associations, and indicate that the designation of a given rock or magma as belonging in the train (*Gefolgschaft*) of certain parent magmas can at most be true only of certain peculiar or aberrent modifications, as a complete statement available for systematic classification.

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[1] "The Petrographic Province of Essex County, Mass.," *Journal of Geology*, Vols. VI and VII (1898, 1899).

[2] "Chemical Analyses of Igneous Rocks, 1884–1900," *Professional Paper No. 14* (1903), U. S. Geological Survey; "The Superior Anlayses of Igneous Rocks from Roth's Tabellen, 1869–1884," *Professional Paper No. 28* (1904), U. S. Geological Survey.

[3] "The Chemical Composition of Igneous Rocks, Expressed by Means of Diagrams, etc.," *Professional Paper No. 18* (1903), U. S. Geological Survey.

WHITMAN CROSS.